

## EXPERIMENTAL STUDY ON MECHANICAL BEHAVIOUR OF CONCRETE BEAMS WITH SHREDDED PLASTICS

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**ABSTRACT:** In recent years, more attention is being paid to alternative disposal of wastes to lessen the harmful impact of these wastes to the environment. In the construction industry, alternative disposal of waste comes in the form of utilization of waste as a substitute construction material. Plastic, typically in the form of plastic bags and bottles, is one of the most abundant wastes in Manila, and, also among the most problematic when it comes to disposal due to its non-biodegradable nature. Hence, more attention is given to alternative use of plastics as a substitute material in construction. In this study, experimental investigation was conducted to assess the performance of concrete beams with shredded plastics, sourced out locally, as a supplementary material. Strength properties of a concrete beam, in terms of compression, tension, and flexure, were investigated for both plain concrete and concrete with shredded plastics. Results showed that concrete with shredded plastics were slightly higher than that of plain concrete in terms of tension and compression strength. Flexural strength of concrete with shredded plastic, also showed higher strength than that of plain concrete. Additionally, this study showed the applicability of elastic flexural theory to concrete beams with plastics.

*Keywords: flexural theory, beam with plastics, alternative concrete component, waste utilization*

### 1. INTRODUCTION

There is a constant, now an increasing, demand for alternative use of waste materials as its management and disposal is worsening with increasing population, continues development, and urban migration. Philippines has not been spared by this and one of the top contributor to this problem in waste disposal is plastics. According to [1], 16% of wastes from Metro Manila are plastics. To make matters worse, Philippines is rated to be among the worst offender in terms of plastic waste disposal as it was ranked 3<sup>rd</sup> among countries in Asia that disposes plastic wastes into the ocean [2].

Apparently, there is an alarming call for a more effective and environment-friendly disposal of plastic wastes. Environmental Protection Agency (EPA) estimated that 13% of total generated wastes are plastics [3]. Only 9% of the total generated plastic wastes, which are about 869,000 tons of plastic estimated annually, are recycled based on [4].

The government, in order to address rising concerns in plastic waste disposal and management, passed and implemented Republic Act 9003 or Ecological Solid Waste Management Act of 2000. This law requires all barangay units to have its own material recovery facility (MRF). However, the implementation of such law had been difficult for many local government units. As reported in [5], many cities found the construction of MRF to be costly, complicated, and would bring foul odor and eye sore. Hence, most cities preferred to have all

wastes hauled and disposed to a landfill located faraway.

The government needs help in combating waste problem in the country. With regards to plastics in particular, the construction industry has initiated some alternative means of disposing plastics by utilizing it as an alternative material in concrete, both locally and globally. Several local studies had been done to look for an alternative use of plastics in construction [6] to [8].

Globally, studies about alternative use of plastics had gained so much ground in the past years. The studies of [9] and [10] have shown that plastics can be used in concrete for gateway support, tunnel linings, light precast elements, and road pavement applications. Others have explored the possibility of using plastics as partial substitute for sand in concrete for structural applications in the hope that the application of this venture can be extended to a wider range of application. The study of [11] explored the influence of using domestic plastic waste, i.e. polythene fibers, in concrete using 0.5% plastic by weight of cement. Results showed that an increase of only 3.84% were observed in compression of concrete cylinders while split tensile strength gained only an increase of 1.63%. Based from [9], where they conducted a critical review of recent studies regarding the use of macro plastic fibers to reinforce concrete, they found that: (1) macro plastic fibres decreases the workability of fresh concrete but limits plastic shrinkage cracking; (2) it has no obvious effects on compression and

flexural strength; (3) and increases ductility of concrete in post-crack region. Reference [12] investigated depolymerized PET (polyethylene terephthalate) plastics used as an alternative binding material in concrete as a partial substitute for Portland cement. Their study compared engineering properties of concrete made up of several variations of PET polymers. According to [13], it investigated the performance of recycled PET fiber reinforced concrete using 0.5%, 0.75%, and 1.0% fiber volume fractions by testing its properties in compression, elastic modulus, and drying shrinkage strain. They compared its performance to that of polypropylene (PP) fiber reinforced concrete. Their study showed that compressive strength and elastic modulus decreases with increasing volume of fiber. However, use of fiber showed improve performance against cracking due to drying shrinkage. Also, structural performance, ultimate strength, and relative ductility were shown to be better with PET fiber reinforced RC beams compared to those without reinforcements. Reference [9] showed that at 1.5% volumetric weight percentage, using PET as fiber reinforcement, resulted to a significant increase in flexural strength.

This study focused on investigating the effect of adding combined shredded local plastic bags (low density polyethylene or LDPE) and plastic bottles (PET), in terms of concrete's mechanical behavior, particularly its flexural behavior to explore the suitability of its application to beam members. It also investigated the applicability of classic flexural theory to concrete with shredded plastics in conjunction with the transformation procedure as suggested by [14]. Theoretical and experimental estimate of flexural cracking capacity is also assessed.

## 2. THEORETICAL BACKGROUND

The classic flexure theory has been shown to be applicable for homogenous beams that behave elastically. Hence, for flexural capacity, cracking moment, and deflection of plain concrete beam, the elastic theory of flexure is adopted in this study.

Motivated by the transformation procedure suggested by [14] where they transformed FRP-reinforced concrete into a single concrete material using the transformation of non-homogeneous elastic beam, this study adopted the same for concrete beams with shredded plastics in calculating for flexural stresses, cracking moment, and deflection.

For concrete with shredded plastics, it is assumed

that the composite section can be transformed into a homogeneous one by transforming shredded plastics into a concrete equivalent. After transformation, the elastic flexure theory will be applied to compute for flexural stresses or flexural capacity. In this study, shredded plastics are uniformly mixed in concrete during mixing, thus, it is assumed that plastics can be represented by a single layer positioned along the centroidal axis. The thickness of the plastic layer is measured, before casting of concrete, by laying down all plastics distributed uniformly in the mold which determines the dimension of plastic in terms of height (or thickness). Modulus of rupture, or the tensile strength of concrete, is based from actual split tensile test of concrete samples.

The area moment of inertia for the "transformed" shredded plastics mixed into concrete is computed based on the following equation:

$$I_{plastic} = \frac{n \times b t^3}{12} \quad (1)$$

where  $I_{plastic}$  = area moment of inertia of a single layer of plastic transformed into concrete,  $n$  = modular ratio,  $b$  = width of beam, and  $t$  = 10mm, the measured thickness of plastics.

The inertia of the whole section, based on the transformed section, is computed as the sum of the moment of inertia of concrete and that of transformed plastic. Flexure formula is then applied to determine flexural stresses.

The following assumptions were further made for this study; (1) the modulus of elasticity for concrete is  $4700 \sqrt{f_c}$ ; ( $f_c$  is taken from actual compression test); (2) the modulus of elasticity for plastic, which typically is within the range of 2.76 – 4.14 GPa, is taken as 3.45 GPa; and (3) the modulus of rupture is taken equal to the tensile strength of concrete from split tensile test.

Theoretical deflection calculations are based on the deflection of a simple beam subjected to concentrated loads applied at third points, and is given by the equation:

$$\delta = \frac{Pa}{24EI} (3L^2 - 4a^2) \quad (2)$$

where:  $\delta$  = deflection at midspan,  $P$  = applied load at third points on a beam,  $a$  = 1/3 of span length,  $L$  = span length,  $E$  = modulus of elasticity of concrete, and  $I$  = moment of inertia of concrete and transformed plastic. All specimens were loaded up to failure.

Table 1. Summary of mechanical properties of plain concrete and concrete with 0.5% shredded plastics

Specimen	Compressive strength (MPa)		Tensile strength (MPa)		Flexural strength (MPa)	
	0% plastic	0.5% plastic	0% plastic	0.5% plastic	0% plastic	0.5% plastic
1	21.81	22.28	3.92	4.00	5.44	6.01
2	21.95	22.21	3.95	4.49	5.58	6.29
3	21.71	22.23	3.98	4.25	5.67	6.88
Average	21.82	22.24	3.95	4.25	5.56	6.39

**3. EXPERIMENTAL SETUP**

Properties needed for the application of elastic flexural theory on beams, with and without shredded plastics, require the determination of mechanical properties of concrete. Hence, compression test, split tensile test, and flexural test, were conducted on concrete specimens.

To represent the typical concrete mix composition of beams being used locally, a water-to-cement ratio of 0.4 was adopted in all concrete specimens, and ACI mix design procedure were adopted to determine the proportions. For concrete with shredded plastics, 0.5% plastics by weight of total samples was used. All specimens were cured for 28 days through immersion in a water bath. Concrete cylinders of size 100mm x 200mm, were casted for both plain concrete and concrete with shredded plastics for a total specimen of 3 per test per type. Tests were done after 28 days of curing and in accordance with [15] ASTM C39 and [16] ASTM C496 procedures.

For flexural properties, 3 rectangular specimens of size 150mm x 150mm x 530mm were prepared for each type and tested after 28 days of curing. Testing were done in accordance with [17] ASTM C78. To measure deflection, a LVDT (displacement transducer) was attached at midspan of the specimen, and successive deflections were recorded.

**4. DATA AND ANALYSIS**

Mechanical properties, in terms of compression, tension, and flexure, derived from experiments for both plain concrete and concrete with shredded plastics, are presented in Table 1. As shown, compressive and tensile properties of concrete with plastics have improved compared to plain concrete. Statistical test, however, have shown that the difference in values between plain concrete and concrete with plastics were not significant. Nevertheless, addition of shredded plastics in concrete up to 0.5%, proved to be not detrimental to the mechanical properties of concrete.

Flexural behavior of beams made up of plain concrete and concrete with plastics were investigated further by determining the cracking moment (Table 2).

Table 2. Cracking moment of beams

Specimen	Measured cracking moment (kN-m)			
	0% plastic	% diff	0.5% plastic	% diff
1	2.09	6.05	2.56	7.10
2	2.04	8.19	2.50	4.45
3	2.10	5.34	2.51	5.11
Theoretical	2.22		2.39	

Comparison between cracking moment capacity of plain concrete and concrete beam with plastic showed an increase in capacity for beams with plastics. Statistical test showed that this increase is significant.

The gap between theoretical deflection and measured deflection was overwhelmingly large, around 250%. As shown in Eq. (2), the theoretical deflection is calculated based on a transformed section with modulus of elasticity (MOE) estimated to be  $4700\sqrt{fc'}$ . This MOE is a code prescribed equation and  $fc'$  is the compression strength from actual tests. The rest of the parameters in Eq. (2) are dependent on the dimension of the section so the gap points out to MOE as the possible cause of the discrepancy. This, however, was no longer investigated by this study.

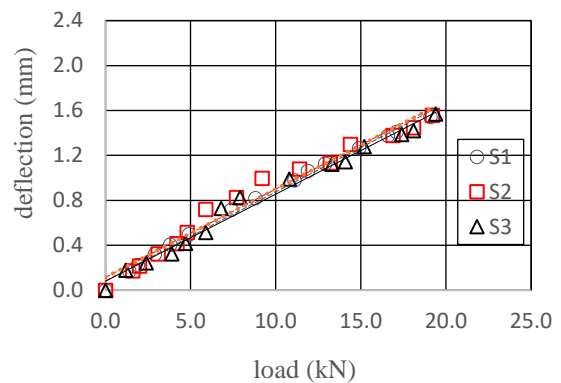


Fig. 1 Load v. deflection for plain concrete beam

Plot of deflection of both beams with plain concrete and concrete with plastics exhibited a linear behavior up to failure. Deflection capacity of beam with plastic was higher (~1.9mm) compared to that of plain concrete beam (~1.5mm).

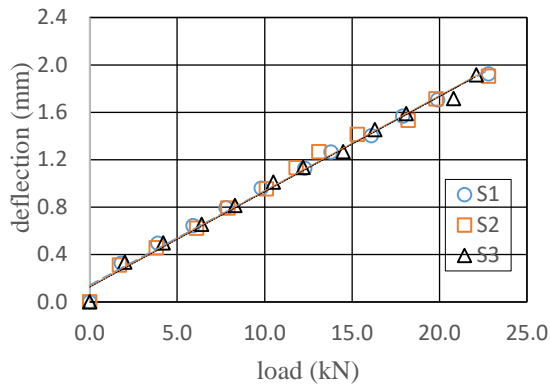


Fig. 2 Load versus deflection for concrete beam with plastics

## 6. CONCLUSION

Waste disposal and management is spiraling out of control in response to country's development. The construction industry is in a perfect position to aid in this problem by utilizing waste as alternative construction material. As shown in this study, plastic waste was incorporated as component of concrete. Its mechanical properties were investigated.

It can be seen that all mechanical properties have shown an increase for concrete with shredded plastics compared to plain and summarized as follows:

- compressive strength: 22.24 MPa v 21.82 MPa;
- tensile strength: 4.25 MPa v. 3.95 MPa;
- flexural strength: 6.39 MPa v. 5.56 MPa;

Though, statistical test showed that the increase was not significant, this increase in mechanical strength is a testament that the addition of shredded plastics, up to 0.5% by weight, is not detrimental to the strength properties of concrete.

Improvements were also observed in flexural behavior of beams with shredded plastics, in terms of cracking moment (2.52MPa v 2.07MPa) and deflection. Statistical test showed that the increase in these properties were significant compared to that of plain concrete.

Another important finding from this study is the comparison between the computed values of cracking moment for concrete with shredded plastics using the classical flexural theory and transformation of concrete with plastics following the procedure adopted from [14]. The agreement between experimental and numerical results have shown a maximum difference of only 8.2% for cracking moment implying that the applicability of elastic flexure theory, and that of transformation by [14] can be extended to concrete with shredded plastics.

The deflection needs to be investigated further as disparity between theoretical and measured values was large. On the other hand, consistency was observed in terms of measured deflection for beams as exhibited by Fig. 1 and 2. For both beams, the one with plain concrete and the one with concrete with plastics, deflection exhibited a linear behavior when loaded up to failure. Measured deflections, for both beams, also showed comparable results with deflection of beams with plastics achieving a slightly higher value than that of plain concrete beam.

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